Northeast Aquatic Research LLC

Lake Hayward Volunteer Water Quality Monitoring Report

Prepared for the Property Owner's Association of Lake Hayward
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Northeast Aquatic Research, LLC ⁘ 74 Higgins Highway, Mansfield, CT 06250 ⁘ 860-456-3179

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Introduction

This was the second year of the Lake Hayward Association volunteer monitoring program, aimed at characterizing lake water quality. The 2020 monitoring included sampling at the beginning of May and the addition of a second monitoring station in the northern section of the lake. Changes to the 2020 sampling design were made to better understand the recent increase in cyanobacteria in the lake.

Sampling Methods

From May through October, Lake Hayward was sampled for water clarity, temperature, dissolved oxygen, and nutrients (Total Phosphorus, Total Nitrogen, Ammonia-Nitrogen, and Nitrate Nitrogen). Water clarity and profile data was collected bi-weekly, and nutrient data was collected monthly. All parameters were collected at the deepest section of the lake. Profiles and water clarity were also recorded at an additional shallow site (3 meters) in the northern section of the lake. Nutrient samples were taken at 1m, 6m, 9m, and 11m at the deep station, with the exception of nitrate-nitrogen, which was only taken at the surface. The 11m sample was also analyzed for Total Iron.

For a detailed explanation of the sampling parameters and their respective importance to an overall water quality monitoring program, please refer to the general "Monitoring Components Descriptions" handouts that we have created for Northeast Aquatic Research (NEAR) clients.

Results

Water Clarity

Clarity consistently declined from spring to summer. End of season clarity increased after lake mixing in 2020, while clarity remained stable through October in 2019. Clarity was consistently worse in 2020 compared to 2019, except during the October sampling.

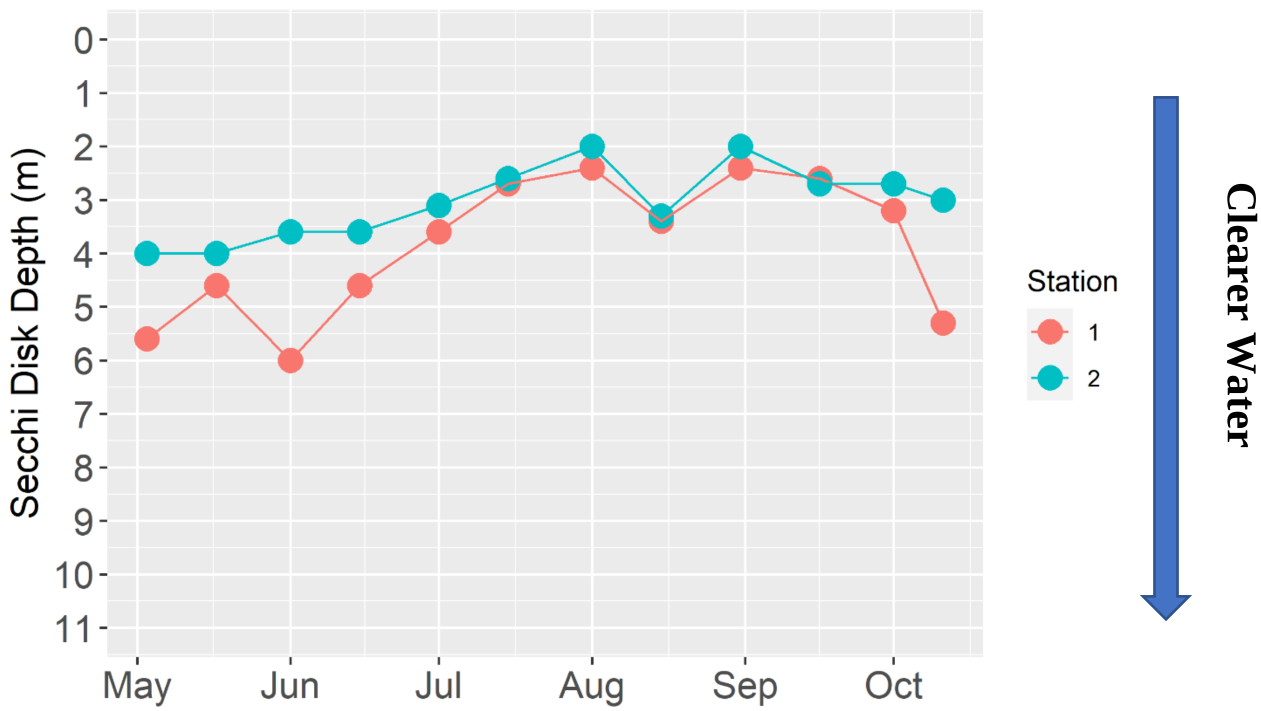

Figure 1. Lake Hayward 2020 Station 1 and 2 water clarity. Note that Station 2 bottom is at 4m.

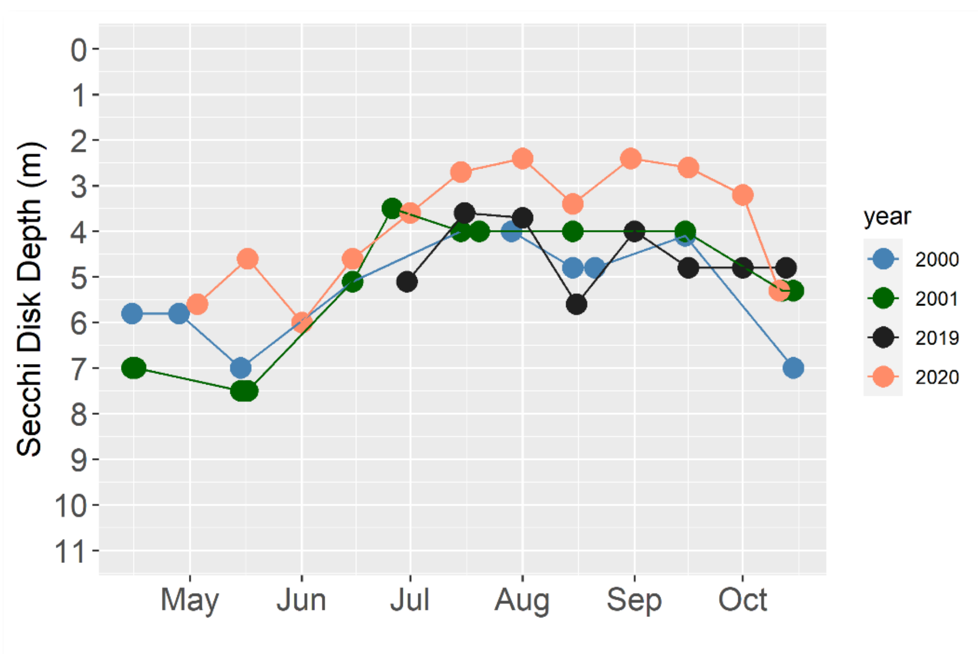

Figure 2. Lake Hayward water clarity over all sampling years at station 1.

Temperature

The highest surface temperature of 2020 (29.5 °C; 85.1 °F) occurred on August 1st. This is relevant because cyanobacteria growth is optimized from 26-31 °C which can help them outcompete greens and diatoms. Temperatures in 2020 were greater or equal to 2019 temperatures except for July 15th.

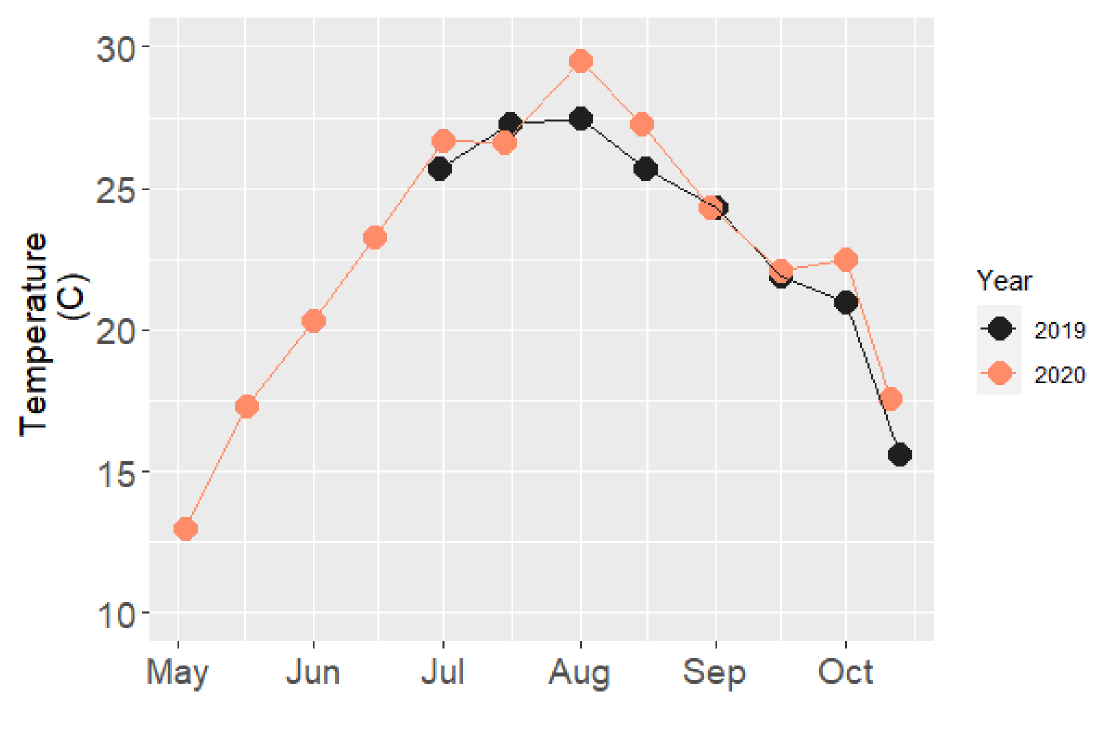

Figure 3. Lake Hayward 2019 and 2020 Station 1 Surface Temperatures.

Stratification began prior to the May 3rd sampling and persisted through October 1st. Lake stratification is the process by which water temperature differences create density gradients and inhibit mixing of the lake's surface and bottom waters. Warmer, less dense water sits on top of colder, denser water, which restricts the bottom waters from surface oxygen replenishment. The top layer is termed the epilimnion and the bottom layer is termed the hypolimnion. The zone of rapid temperature change, where temperature is decreasing more than 1°C per meter is referred to as the metalimnion. The depth of largest temperature change is termed the thermocline, which regulates chemical and biological processes in lakes.

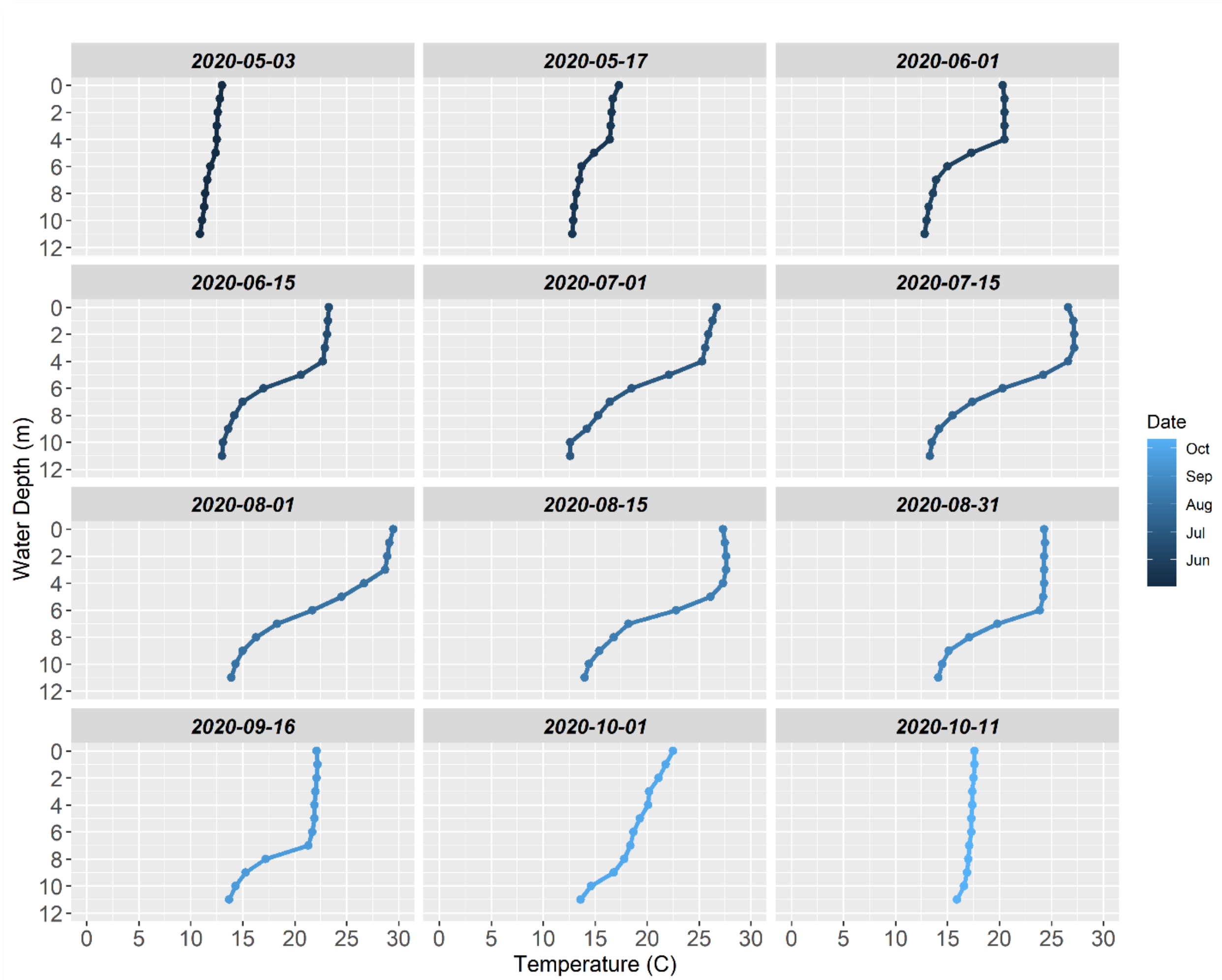

Figure 4. Lake Hayward 2020 Station 1 Temperature Profiles.

The thermocline deepened as the season progressed, which is typical of stratified lakes. The size of the metalimnion increases as the season progresses, with the widest section observed on August 1st. The sizes of the three distinct layers (epilimnion, metalimnion and hypolimnion) can either increase or decrease throughout the season depending on heat, wind and biological factors. Wind mixing can push the epilimnion deeper into the water column, shrinking the size of the metalimnion and hypolimnion. Conversely, decreases in water clarity can shrink the size of the epilimnion due to the suspended particles in the water absorbing heat and light, which in turn can increase the metalimnion size. A widened metalimnion, which coincides with the shrinking of the hypolimnion, can allow for increased transport of nutrients from the bottom waters to the surface.

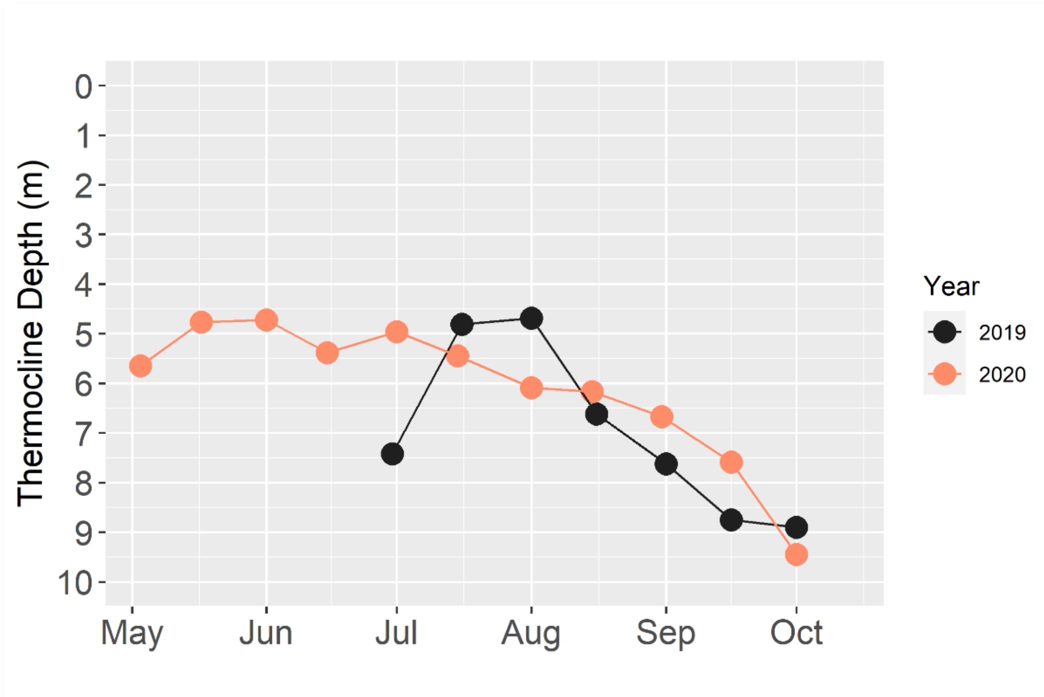

Figure 5. Lake Hayward 2020 and 2019 Thermocline depth. Thermocline is defined as the zone of maximum thermal gradient; i.e. the largest difference between two temperature readings at depth.

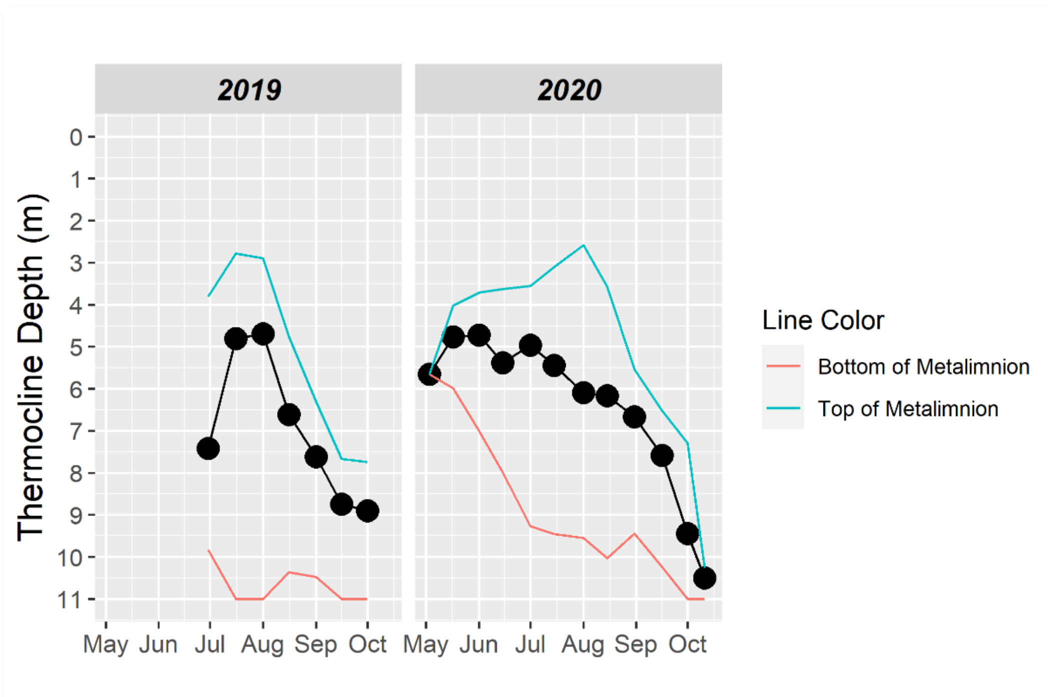

Figure 6. Lake Hayward 2020 and 2019 Thermocline depth with the top and the bottom of the metalimnion delineated. The metalimnion is the zone of temperature change which contains the thermocline. The areas above the blue line and below the red line have temperature changes less than 1 °C with depth.

Oxygen

Oxygen began to deplete at the bottom of the lake in early June and was anoxic by July 1st. Anoxia persisted from the first of July to the middle of October. Oxygen depletion commonly continues after the lake is thermally mixed in the fall. The depth of the anoxic boundary increased as the summer progressed, with the shallowest anoxic depth being observed on August 1st.

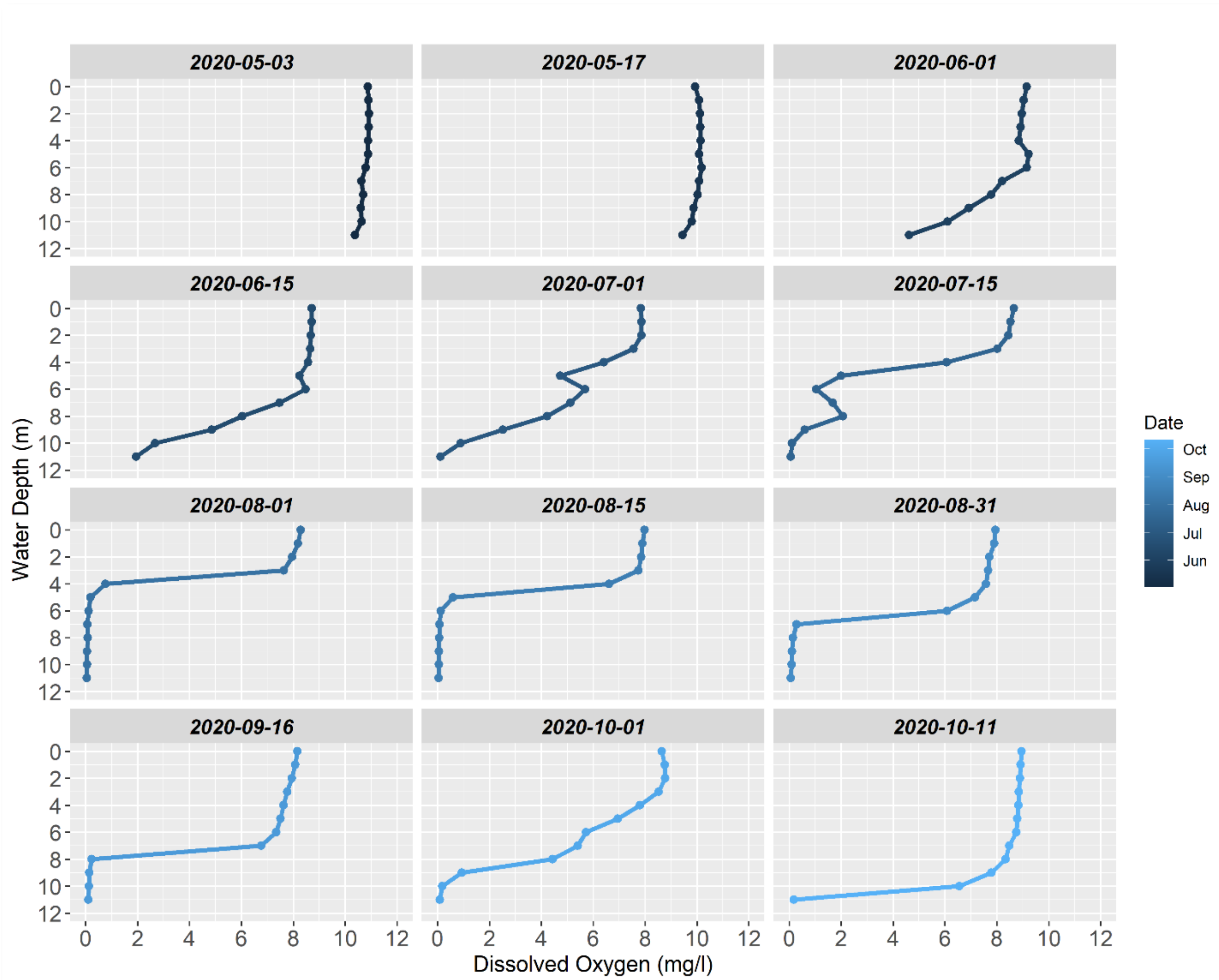

Figure 7. Lake Hayward 2020 Station 1 Percent Oxygen Saturation.

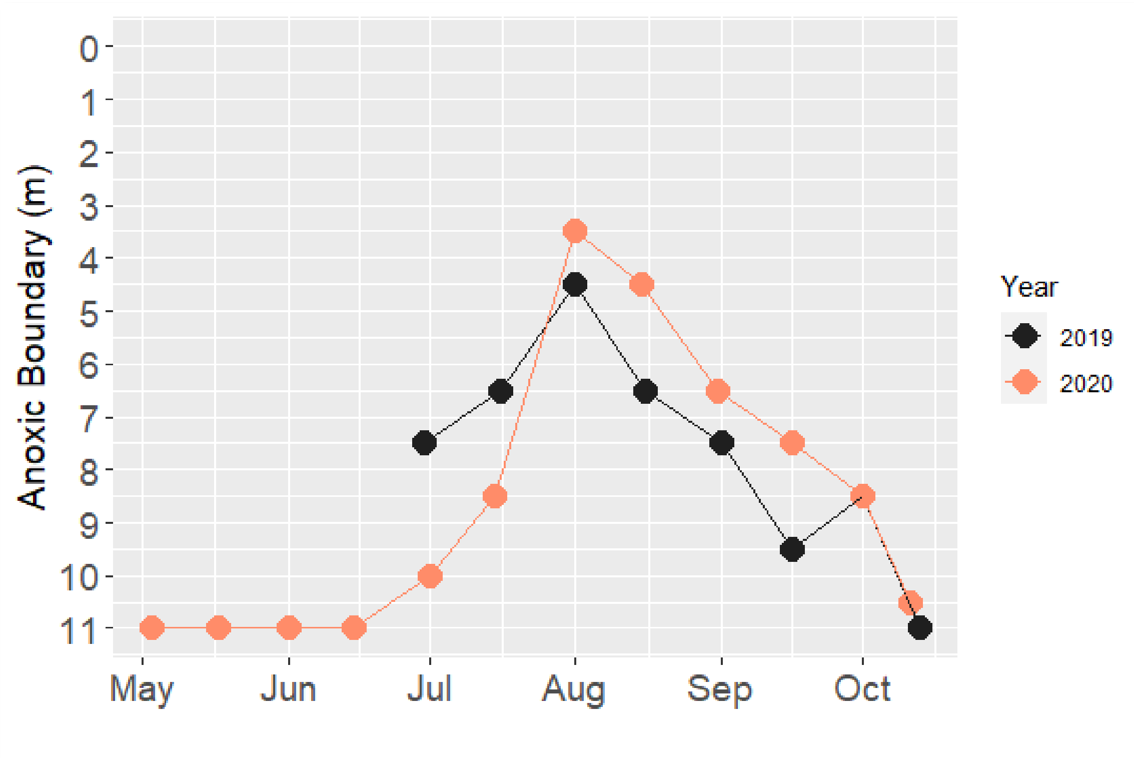

Figure 8. Lake Hayward 2019 and 2020 Station 1 anoxic boundaries. The anoxic boundary is defined as the shallowest depth with <1mg/l of oxygen.

As the depth of the anoxic boundary increases, the total amount of sediment that is actively releasing nutrients into the water column increases as well. We can estimate the total area of anoxia from the anoxic boundaries from our profiles from both stations (Figures 9 and 10). Anoxic area increases throughout the season with the largest sediment area exposed to low oxygen conditions documented on August 1st (56 acres of exposed sediment).

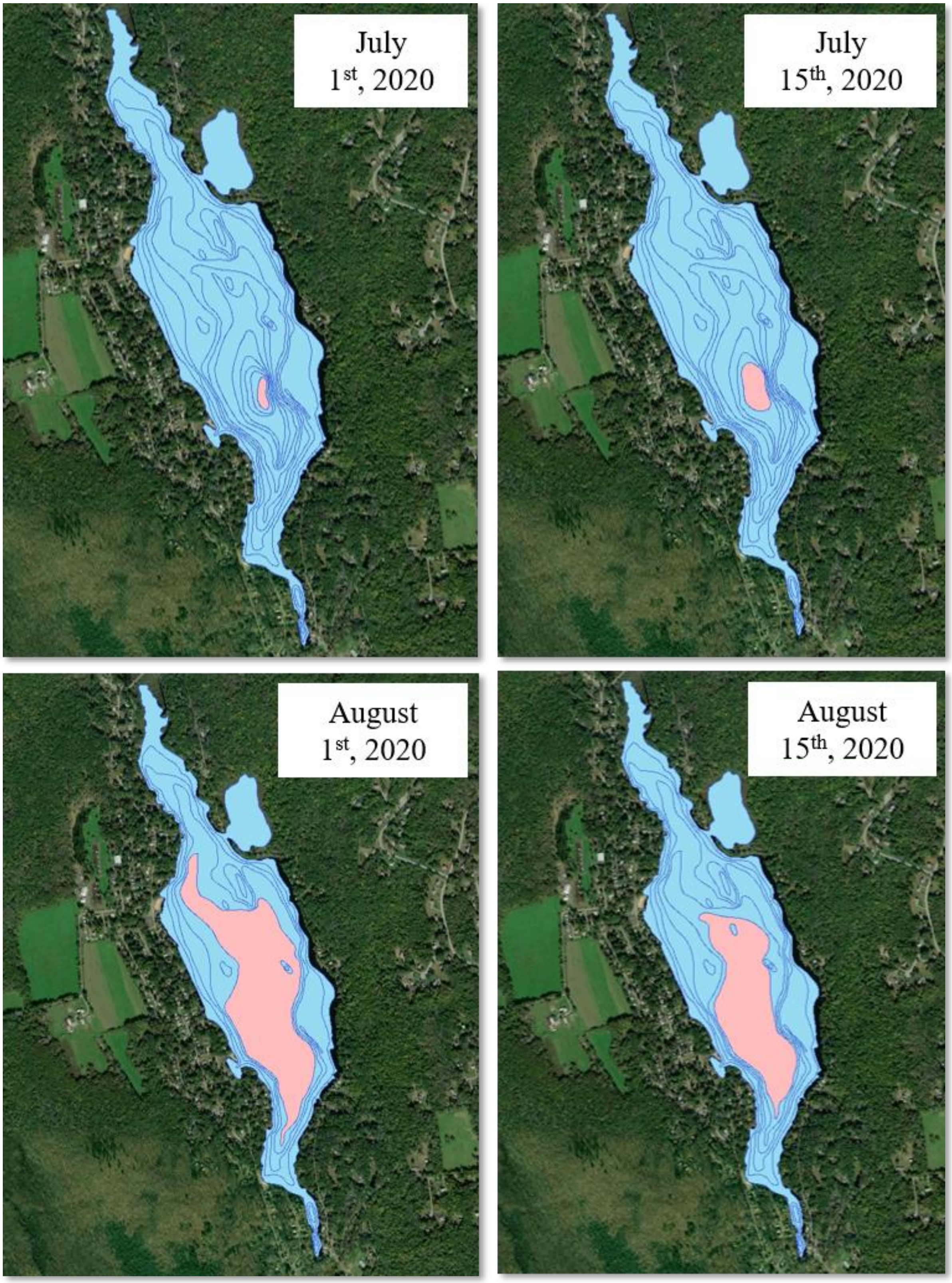

Figure 9. Lake Hayward 2020 extent of anoxia July 1st to August 15th. Red shaded area indicates the estimated sediment area which is in contact with <1 mg/l of oxygen.

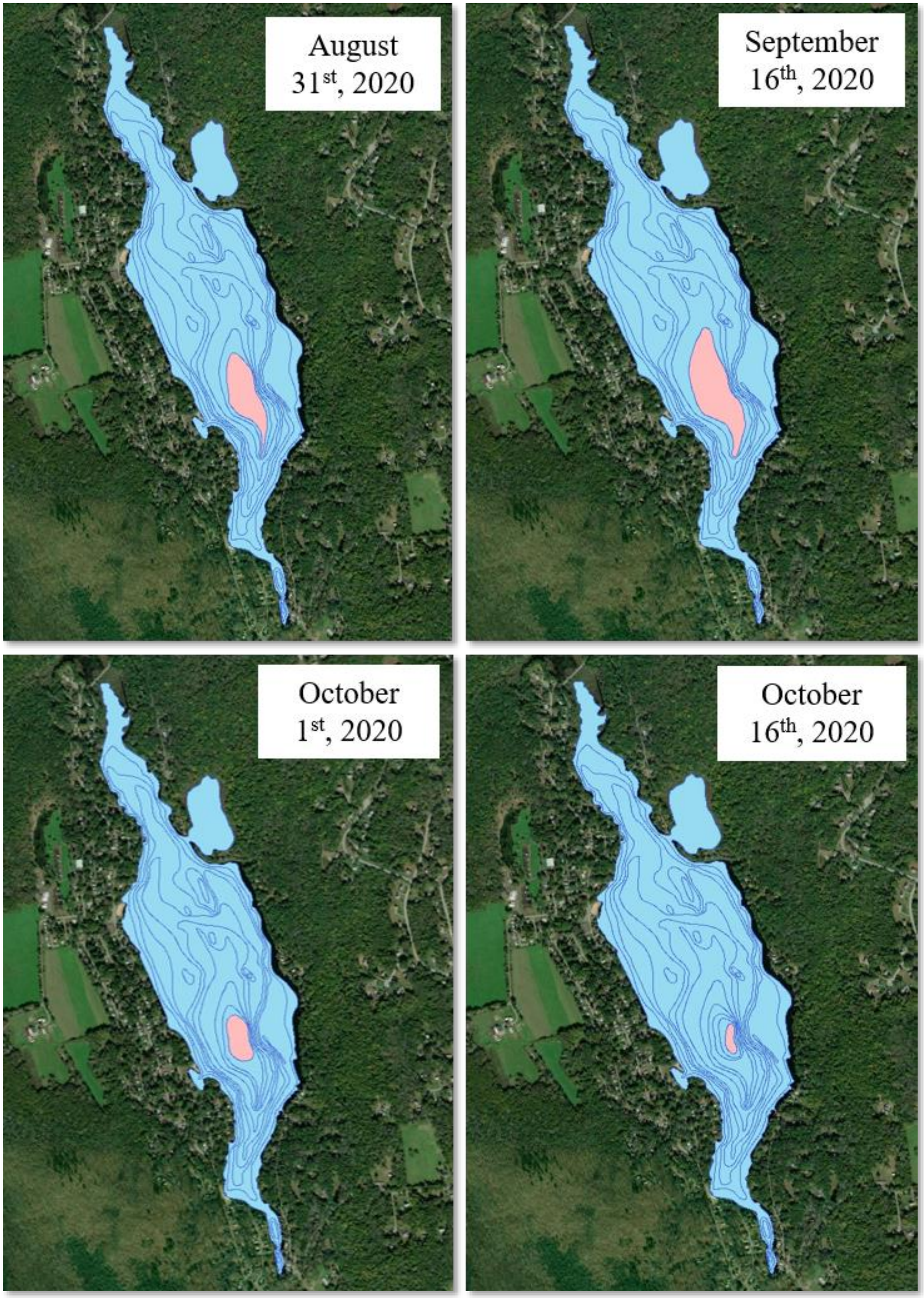

Figure 10. Lake Hayward 2020 extent of anoxia August 31st to October 16th. Red shaded area indicates the estimated sediment area which is in contact with <1 mg/l of oxygen.

Nutrients

Surface total phosphorus increased as the summer progressed, with the highest value being found during the August 13th sampling event. Both surface phosphorus and surface nitrogen were higher in 2020 than in 2019, consistent with the worsened clarity in 2020. The 2020 bottom phosphorus remained low until August 31st, when it was measured at a concentration of 215 ug/l. Total iron was also highest at this time, indicating internal release of iron-bound sediment phosphorus.

Both surface phosphorus and surface nitrogen were higher in 2020 than in 2019. However, bottom phosphorus and especially bottom nitrogen overall, were lower in 2020 versus 2019. We believe that the extended anoxic boundary in 2020 allowed for transport of nutrients from the bottom waters into the surface via wind mixing and/or algae movement.

Table 1. Nutrient Results from 2020 Sampling. TP = Total Phosphorus, TN = Total Nitrogen, NH3 = Ammonia-Nitrogen, NOx = Nitrate-Nitrogen, Fe = Total Iron.

Depth	Date	NH3 (µg/l)	NOx (µg/l)	TN (µg/l)	TP (µg/l)	Fe (µg/l)
1	5/2/2020	7	172	297	14	--
6		9	--	280	16	--
9		9	--	271	13	--
Bottom		14	--	285	32	556
1	6/1/2020	26	106	310	15	--
6		11	--	234	16	--
9		33	--	272	16	--
Bottom		66	--	312	15	154
1	7/1/2020	28	40	239	17	--
6		52	--	158	12	--
9		92	--	259	21	--
Bottom		212	--	322	30	547
1	8/1/2020	5	5	259	19	--
6		237	--	399	18	--
9		376	--	481	17	--
Bottom		300	--	455	16	348
1	8/31/2020	30	5	274	21	--
6		93	--	315	18	--
9		611	--	538	21	--
Bottom		386	--	587	215	7731
1	10/1/2020	49	15	283	13	--
6		120	16	309	12	--
9		357	6	390	16	--
Bottom		410	6	406	14	1452

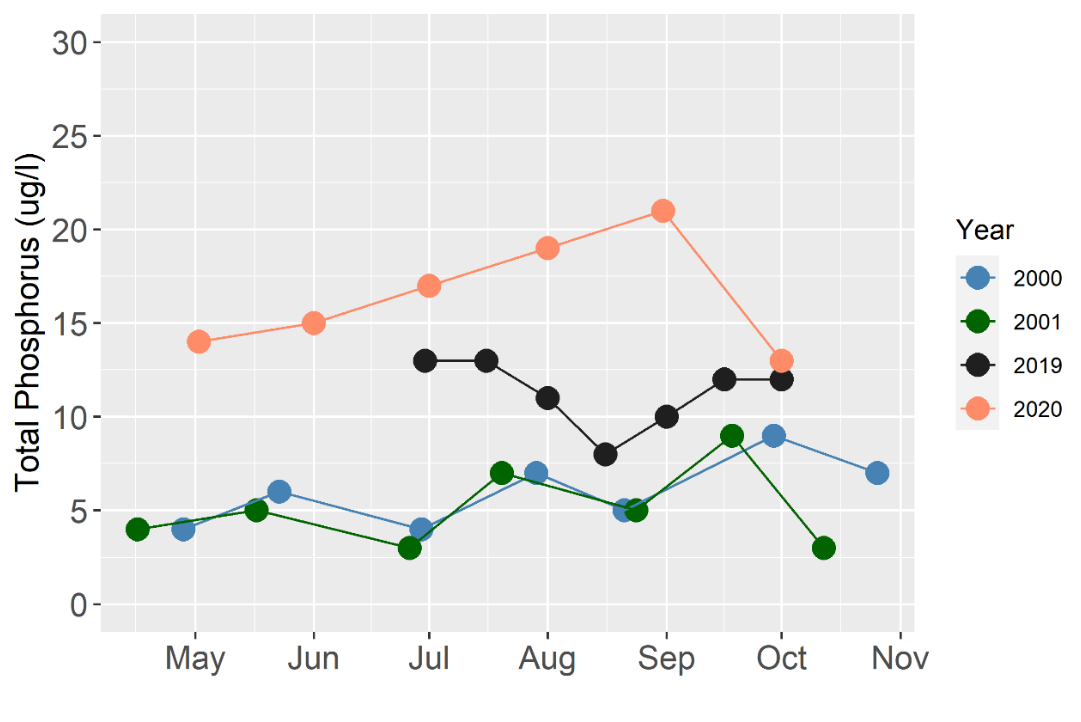

Figure 11. Lake Hayward Station 1 surface total phosphorus.

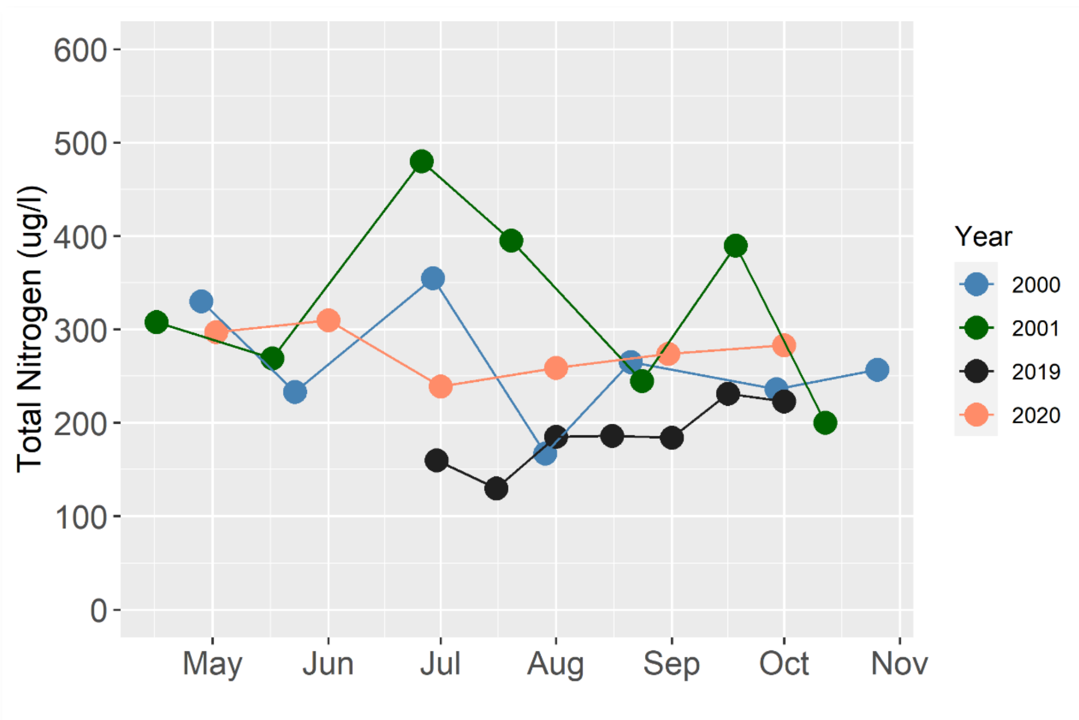

Figure 12. Lake Hayward 2019 and 2020 Station 1 surface total nitrogen.

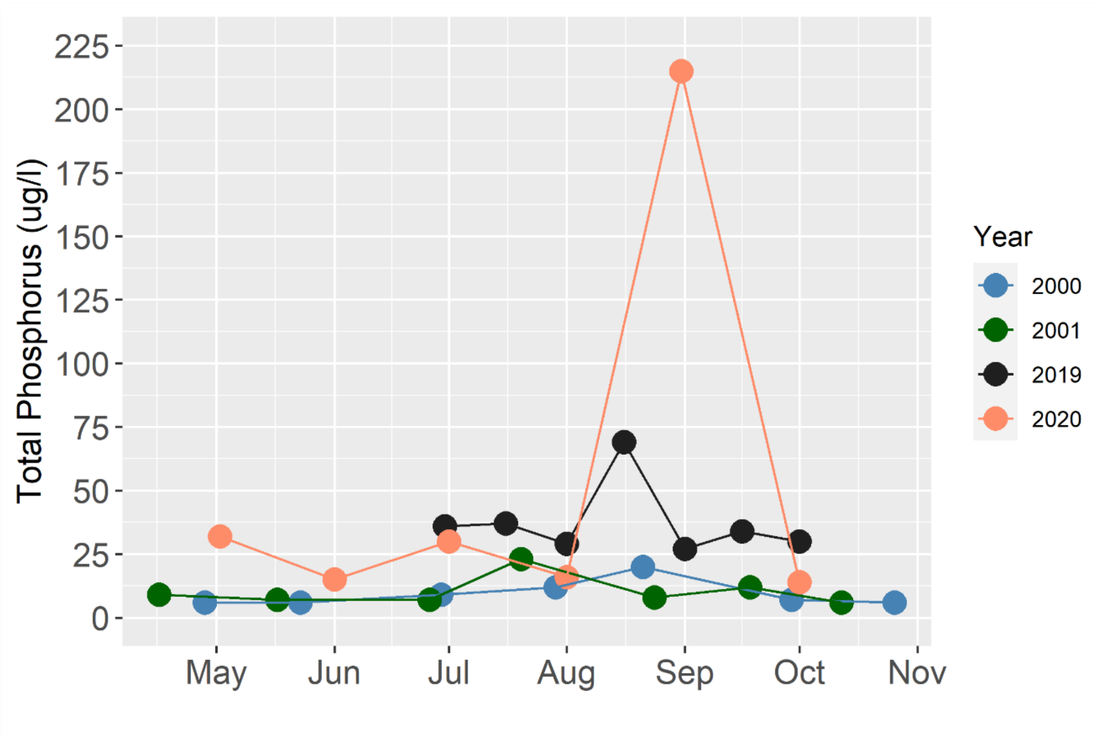

Figure 13. Lake Hayward 2019 and 2020 Station 1 bottom total phosphorus.

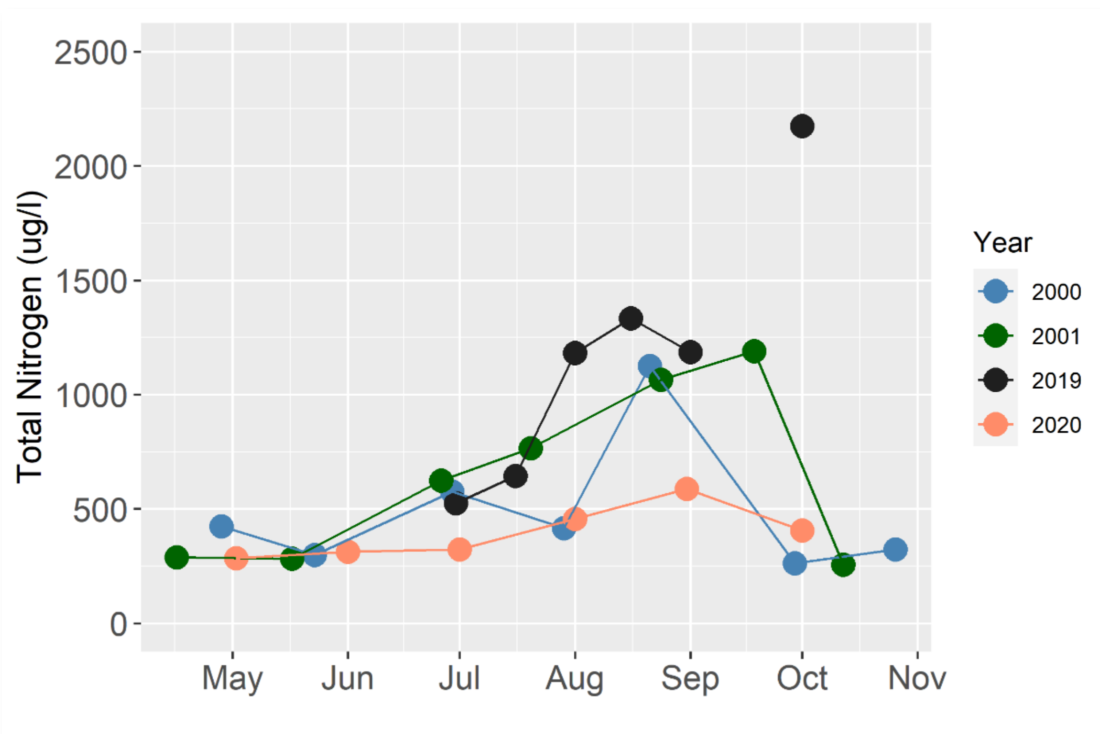

Figure 14. Lake Hayward 2019 and 2020 Station 1 bottom total nitrogen.

Sediment Phosphorus Sampling

NEAR staff sampled Lake Hayward sediments in the fall to assess the phosphorus content and to estimate the total amount of phosphorus being internally loaded into the lake water during the 2020 season. Three samples were taken at three different depths throughout the lake using an Ekman dredge. Samples were shipped to IEH laboratories in Seattle, Washington for phosphorus determination and fractionation. The laboratory utilized the sequential phosphorus extraction methods outlined in Rydin and Welch 1998[1].

Table 2. Sediment total phosphorus concentrations and fractionations. Values are in mg/kg.

Sample Depth	Total_P	Loosely Bound_P	Fe_bound_P	Al_Bound_P	Biogenic_P	Ca_Bound_P	Organic_P
36ft	2822	< 2.00	998	1149	399	57.9	617
25ft	2216	< 2.00	547	948	479	29.7	691
19ft	1784	< 2.00	257	788	359	25.8	713

[1]Rydin, E. and Welch, E.B., 1998. Aluminum dose required to inactivate phosphate in lake sediments. *Water research*, *32*(10), pp.2969-2976.

Internal Phosphorus Loading Estimate

The average sediment phosphorus release rate (RR) was calculated using the equation from Nurnberg 1988[1] and the mean sediment phosphorus concentration.

$$\log RR = 0.80 + 0.76 \log(\text{Sediment TP})$$
$$RR = 11.7 \text{ mg/m2/day}$$

We chose to use the sediment release model rather than the laboratory release rate experiments due to the cost, logistics and error associated with simulated release versus in field observed release. The release rate was applied to the estimated area of anoxic sediment during each sampling date to estimate the aerial release rate for phosphorus via anoxic sediment release. Area of anoxic sediment was calculated using the 1998 bathymetry contours provided by the CT DEEP combined with the anoxic boundary during the particular sampling date. To estimate the total amount of phosphorus being released from the sediment during anoxic conditions, we multiplied the average release rate by the estimated number of days where the sediment was anoxic.

Average aerial phosphorus release rate: 0.74 kg/day
Estimated number of days that there was anoxia: 108
Total phosphorus released during anoxia: 80 kg

Table 3. Area of anoxic sediments and aerial release rate for Phosphorus.

Date	Area of Anoxic Sediment (Acres)	Aerial P Release Rate (kg/day)
July 1st	0.9	0.05
July 15th	3.8	0.18
August 1st	56.8	2.68
August 15th	38.7	1.83
August 31st	7.8	0.37
September 16th	12.7	0.60
October 1st	3.8	0.18
October 16th	0.9	0.04

Average phosphorus release rate: 0.74 kg/day
Total days of anoxia: 108 days
Estimated total phosphorus released during anoxic period: ~80 kg

[1]Nürnberg, G.K., 1988. Prediction of phosphorus release rates from total and reductant-soluble phosphorus in anoxic lake sediments. *Canadian Journal of Fisheries and Aquatic Sciences*, *45*(3), pp.453-462.

Phytoplankton

Phytoplankton during the 2020 season was dominated by blue-green algae from July to October. The most dominant cyanobacteria genera fluctuated, with *Microcystis* dominant during July and *Woronichinia* most prevalent in September and October. Both genera are known to produce cyanotoxins. The amount of toxins is related to the severity of the bloom and potential wind-blown accumulation on shores. Shoreline scums have the highest potential for toxin accumulation, which is a direct result of wind-blow accumulation of a very high concentration of cells per mL. It is rare for cyanotoxins to be present at concentrations that are harmful to human health in open water without scums. Scums in open water are possible, however, particularly on very calm, hot days.

Figure 15. Accumulated cyanobacteria scums on Lake Hayward.

Table 4. Counts of algae groups (cells per ml)

Date	Blue Green	Greens	Diatoms	Chrysophytes
6/1/2020	0	510	0	0
7/1/2020	16,603	0	0	0
8/31/2020	14,359	175	0	15
10/1/2020	25,948	146	146	0

Table 5. Counts of cyanobacteria genera (cells per ml)

Date	*Dolichospermum*	*Woronichinia*	*Gleocapsa*	*Microcystis*	*Planktothrix*	*Chroococcus*
6/1/2020	0	0	0	0	0	0
7/1/2020	0	0	131	16,472	0	0
8/31/2020	0	12,959	0	0	292	1,108
10/1/2020	0	25,948	0	0	0	0

Notifications of algae scums should be relayed to all residents once visually identified. Proper public posting and notification should follow the CT DEEP/DPH blue-green algae guidance document: https://portal.ct.gov/DPH/Environmental-Health/Environmental-Health-Section/Blue-Green-Algae-Blooms.

Overall Water Quality Discussion

The Lake Hayward water clarity, anoxic boundary, and surface nutrients were all worse in 2020 compared to 2019. Interestingly, bottom nutrients were lower in 2020 versus 2019.

One possible explanation for this is an increased entrainment of hypolimnetic nutrients into the shallower water depths (meta- and epilimnion). This increased movement of deep-water nutrients would result in worsened surface conditions and subsequently lower bottom-water nutrients if the rate of internal loading did not change significantly from 2019 to 2020. Increased entrainment of nutrients can occur when an anoxic boundary extends into the metalimnion/thermocline area, which was the case in 2020. Significant wind mixing events also periodically entrain bottom-water nutrients to the surface. In the case of Hayward, it is also likely that nutrient entrainment was aided by the migration of cyanobacteria from deeper waters to the surface waters.

Cyanobacteria are well known for regulating their buoyancy based on their use and storage of carbohydrates. This process allows them to move downwards and use nutrients in deeper waters, after which they are then able to return to shallower water in search of increased light and temperature to continue to grow. Some species of cyanobacteria also start growing on the lake sediments, from resting-stage cells called akinetes. In both cases, cyanobacteria can accumulate nutrients before rising to the surface. If there was a lake wide migration of cyanobacteria from deeper waters, that would cause a large movement of nutrients and subsequent decrease in water clarity similar to what was seen in 2020.

It is important to note that the transport of nutrients to the surface will be heavily affected by dilution. For example, if the bottom water has 2000 ug/L of nitrogen, that mass of nutrients will be mixed into a much larger volume of water near the surface, which dilutes the concentration. As a result, the concentration in the surface will only increase slightly after nutrient entrainment events, despite a large decrease in the bottom water concentration.

To elaborate on the wind mixing impacts on bottom-to-surface nutrient entrainment we will refer to the Osgood index[1]. The Osgood index is the ratio of mean depth to the square root of the lake surface acres, which allows us to quantify the relative impact of wind mixing on the lake. Osgood values greater than 6-7 indicate strong stratification and resistance to wind forces mixing the lake. The Osgood index for Lake Hayward is 4.01, indicating the potential for wind mixing to play a significant role in nutrient movement from bottom waters. Hayward has a deep spot of 36 feet, but that represents a small sediment area. Around 75% of the total surface area of the lake is less than 15 feet deep.

We also believe that the watershed plays a role in decreased clarity and algae blooms. The clarity first started to decline from June 1st to June 15th, even though anoxia did not begin until the beginning of July. This early season decline in water clarity can be partially attributed to watershed inputs and increasing lake temperatures, as there was presumed to be little to no internally loaded nutrients in spring. Both internal and external nutrient sources should be addressed in the long-term Lake Hayward management effort.

Internal Loading Estimate

The estimated total amount of phosphorus entering the lake during anoxic conditions needs to be considered in the context of the entire annual load into Lake Hayward. The watershed plan indicated that 1,470 lbs. of phosphorus is loaded annually into Lake Hayward from the watershed. If we take into account the internal loading (which is roughly 176 lbs./year), the percentage of the Total phosphorus load coming from internally loaded phosphorus is only 12%. While this may seem like a small percentage, it likely undersells the contribution of internal loading to cyanobacterial growth.

[1]Osgood, R.A., 1988. Lake mixis and internal phosphorus dynamics. *Archiv Für Hydrobiologie*, *113*(4), pp.629-638.

The chemical form of phosphorus and nitrogen from internal versus external sources is critical. For example, phosphorus that enters the lake via stormwater is mostly bound to minerals and/or incorporated into organic materials, neither of which are available for immediate phosphorus uptake by algae. Internally loaded phosphorus from anoxic sediments, however, is present in a dissolved form, which is readily bioavailable for algae growth. Similarly, cyanobacteria grow in open water are known to get a large fraction of their nutrient supply from deeper-waters and near the thermocline. In addition, the anoxic internal load occurs during the summer months, when light and temperature are most optimal for algae growth. In contrast, watershed loading is normally higher during the spring and fall seasons.

The aforementioned factors illustrate that the contribution of the internal load compared to the external load is not as simple as the 12% contribution implies. It is also very possible that the watershed load estimate is an overestimate, as different models used in other watershed loading calculations from similarly sized watersheds are not usually quite so high.

Furthermore, the total load from the watershed is based on an annual estimate, while the internal loading occurs entirely within three and a half months during the summer. There is also a smaller, but not absent, oxic (in the presence of oxygen) load of phosphorus that takes place both during the summer in shallow waters and throughout the entire lake during the spring, fall, and most of the winter. Oxic release includes wind mixing and turbulence at the sediment-water interface, movement of burrowing invertebrates, and microbial respiration and decay of organic matter. While this is extremely difficult to quantify using standard field data, we can infer that these methods are playing some role in phosphorus release.

Recommendations for 2021

- Continue to monitor lake conditions along with watershed inputs. Watershed input monitoring includes testing from select inflows and periodic stormwater sampling.
- Move the second station to slightly deeper water (6 meters) to capture the extent of anoxia in shallower waters.
- Continue to visually monitor the beaches and shoreline for harmful algae blooms. An early warning system should be put into place to alert the community to potential harmful algae bloom conditions via email. Confer with the Chatham Health District and follow their guidance in establishing a protocol for dealing with potential harmful algae blooms.